Over the Pole: A Fuel Efficiency Analysis of Employing Joint Base Elmendorf-Richardson for Polar Route Utilization

GRADUATE RESEARCH PROJECT

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AFIT-ENS-GRP-14-J-15

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENS-GRP-14-J-15

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GRADUATE RESEARCH PROJECT

Presented to the Faculty

Department of Operational Sciences

Graduate School of Logistics and Air Mobility

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in in Logistics

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June 2014

AFIT-ENS-GRP-14-J-15

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Abstract

The goal of this research is to determine which current US C-17A base is situated in the best geographic location to quickly and simultaneously support the Areas of Responsibility of Pacific Command, European Command and Central Command while providing the maximum cargo throughput in the most fuel efficient manner. The researcher hypothesizes that Joint Base Elmendorf-Richardson sits close to the potentially under-utilized polar route structure which could deliver fuel efficiencies. The research focused on the fuel efficiency rating of cargo missions originating from 6 US C-17A bases en route to numerous validated channel mission destinations. A maximum payload fuel efficiency rating is calculated by running each origin/destination pair through a Route Analyzer model. A weighted frequency based maximum payload fuel efficiency rating is then calculated by using a P-center location theory model ranking the 6 US bases by their overall score. Based on the assumptions of this research, the analysis shows that Joint Base Elmendorf-Richardson is the ideal location to stage C-17A airlift operations in order to efficiently reach the most destinations in Pacific Command, European Command and Central Command from the same origin due to its proximity to the polar route structure.

To Heather, Evan and Adriana

Acknowledgments

Thank you to all of the experts at USTRANSCOM and AMC who provided me with critical information to make this project possible. Also, thanks to Pamela Bennett Bardot for helping me with research, as well as Lt Col Adam Reiman for the use of his modeling software. Both were critical components to help complete this project. I would like to express my sincere appreciation to my advisor, Dr. Jeffery Weir, and my sponsor, Lt Col Stephen Hodge, for their guidance, support, and feedback throughout the year.

Hugh P. Sponseller

Table of Contents

List of Figures

List of Tables

I. Introduction

Background

> "It's been long recognized in the air mobility community that a major limiting factor on deployment operations is not the number of available aircraft or crews, but rather the capability of the en route or destination infrastructure to accommodate the throughput requirements of mobility aircraft. To overcome these limitations, future air mobility forces will emphasize using aircraft with greater unrefueled range, decreased reliance on en route infrastructure support, decreased mobility footprint at forward locations" (Air Mobility Command, 2011)

With continuing operations in Afghanistan, the Pacific rebalance, and increasing Russian provocations in Eastern Europe occurring simultaneously, the Air Force must be poised to respond quickly to multiple geographic Areas of Responsibility (AOR) throughout the globe. Air Mobility Command (AMC) must also be ready to provide airlift in order to support Combatant Commanders (CCDR) needs on a moment's notice anywhere in the world. However, meeting these airlift requirements is not an easy task and it has been further limited by an era of defense budget reductions and sequestration.

In today's constrained fiscal environment all options to reduce fuel consumption and still complete the mission must be explored and carefully considered. Reducing fuel consumption is an effective tactic in battling budget reductions and will make the Air Force more efficient in the long run. In his article for *Air Transport World*, Geoffrey Thomas pointed out, "the opening of new polar routes is certainly the most dramatic step to increase system capacity and efficiency, and thereby reduce operating costs" (Thomas, 2001). The polar route structure has been utilized by the commercial carriers for years to reduce distance flown, and ultimately fuel consumed, but it is potentially under-utilized by AMC. As the Afghanistan retrograde continues and the US military's strategic shift to Asia matures, there are new cost savings opportunities available by using polar flight routes. Although AMC has used the polar routes in a limited capacity for cargo and crew rotations, all the cost savings potential have not been thoroughly explored.

Joint Base Elmendorf-Richardson's location in Alaska allows quick access to the polar route structure which makes it an ideal air cargo hub location. By hosting cargo operations out of Alaska, the United States Transportation Command (USTRANSCOM) can use the C-17A to quickly provide strategic airlift support to the Areas of Responsibility (AOR) of Pacific Command (PACOM), Central Command (CENTCOM), and European Command (EUCOM) simultaneously from the same location.

Problem Statement

There are many hot spots throughout the world that the US military supports on a short term and continuing basis. Since Rapid Global Mobility is a distinctive capability of the United States Air Force it is important for the Air Force to be able to react quickly to emerging threats throughout the world. The 2010 Air Mobility Master Plan states, "Regardless, whether hunting down terrorists overseas or defending U.S. interests at home and abroad, mobility responsiveness will be required in order to meet the challenges of the future environment" (Air Mobility Command, 2010). This global problem is compounded by a steady decline in military spending. The Air Force spends $9 billion in energy consumption each year with 81% of that expenditure being aviation fuel (United States Air Force, 2013). In order to rapidly support operations throughout the world as well as reduce fuel consumption the Air Force must look at ways to employ strategic airlift in the most fuel efficient manner possible. This research project examines which US C-17A base is the most ideal location to quickly provide strategic airlift to the AORs of PACOM, CENTCOM, and EUCOM simultaneously in the most fuel efficient manner.

Research Objectives/Questions/Hypotheses

The goal of this research is to determine which current US C-17A base is situated in the best geographic location to quickly and simultaneously support the Areas of Responsibility (AOR) of PACOM, CENTCOM, and EUCOM while providing the maximum cargo throughput in the most fuel efficient manner.

Throughout the research there are three questions that need to be answered to effectively satisfy the requirements of the project. They include:

1. Are there current C-17A bases that are not able to efficiently provide strategic airlift support the AORs of PACOM, CENTCOM, and EUCOM simultaneously?

2. Does the use of polar routes increase the efficiency of strategic airlift operations servicing the AORs of PACOM, CENTCOM, and EUCOM?

3. Which US C-17A base can most efficiently provide strategic airlift support simultaneously to the AORs of PACOM, CENTCOM, and EUCOM?

There are 2 potential hypotheses that are explored in this project. First (H1), it is more efficient to originate airlift missions from Joint Base Elmendorf-Richardson than other North American C-17A bases to quickly and simultaneously support the Areas of Responsibility of PACOM, CENTCOM, and EUCOM in a more fuel efficient manner when compared to other Continental United States (CONUS) bases. Second (H2), airlift missions that originate from Joint Base Elmendorf-Richardson can deliver cargo to

PACOM, CENTCOM, and EUCOM efficiently because of its proximity to the polar route structure.

Research Focus

This research is focused on performing a comprehensive analysis to determine potential fuel efficiency benefits and/or strategic viability of using Joint Base Elmendorf-Richardson as an airlift hub to quickly and simultaneously support the Areas of Responsibility of PACOM, CENTCOM, and EUCOM because of its reduced distance to those AORs enabled by its access to polar routes. This project focuses on the fuel efficiency rating of cargo missions originating from 6 US based C-17A units en route to numerous validated channel mission destinations.

Methodology

Research for the project is focused on quantitative data. The methodology of procuring this data includes a thorough literature review, a review of channel operations data, route analysis modeling, and location theory modeling. This research focuses on 6 US C-17A bases, 3 on the East coast of the US and 3 on the West coast of the US. After the 6 bases were selected they were run through an Air Force Institute of Technology (AFIT) route analyzer program in order to determine which location provided the highest maximum payload fuel efficiency rating to 27 locations within EUCOM, CENTCOM, and PACOM. The unitless maximum payload fuel efficiency rating is calculated by determining the cargo throughput per day divided by the fuel consumed per day based upon loading the maximum payload.

After the data from the route analyzer was compiled it is next run through a P-center model which determined the largest maximum payload fuel efficiency rating then multiplied the result with a frequency multiplier. The frequency multiplier is determined by the frequency in which channel missions passed through each destination over the last 3 years. The result of the model produces a unitless frequency based maximum payload fuel efficiency rating. The rating of each origin is compared each other to determine which origin location has the largest frequency based maximum payload fuel efficiency rating. This results in the most optimal airlift origin to provide support to the AORs of EUCOM, PACOM and CENTCOM simultaneously.

Assumptions/Limitations

Assumptions:

- International agreements will not change during the analysis
- Capacity requirements can be met
- External airfield factors including inclement weather will not hinder operations
- Reduction in fuel usage will lower operational costs
- Polar route considerations such as volcanic activity and fuel freezing issues will not affect flight operations in the Arctic region
- Required cargo will be available at the origin prior to each airlift mission

Limitations:

- International agreements
- Diplomatic clearances
- Most cargo hubs are East coast based

Implications

This study's results will assist AMC, PACAF, PACOM, CENTCOM, EUCOM and USTRANSCOM leadership in making informed cost saving decisions for future requirements. Ultimately, this study's objective is to enable our leaders to answer confidently the question "which US C-17A base is the most ideal location to quickly support the AOR of PACOM, CENTCOM, and EUCOM simultaneously in the most fuel efficient manner?" now and for future operations.

II. Literature Review

Chapter Overview

The objective of this literature review is to provide a comprehensive overview of all the related information that will guide this research project.

Fuel Efficiency

In March 2013 the Air Force released the U.S. Air Force Energy Strategic Plan in order to develop and maintain a comprehensive energy strategy. The strategy provides provisions for energy security and operational energy as well as assists the Air Force with compliance with legislative provisions, executive orders and DOD directives (United States Air Force, 2013). As military fiscal constraints continue, the Air Force has been forced to be internally critical of its own energy usage. The Energy Strategic Plan attempts to provide priorities and a roadmap to rein in energy usage (United States Air Force, 2013).

The plan describes the Air Force's energy priorities (Figure 1) as improving resiliency, reducing demand, assuring supply, and to foster an energy aware culture (United States Air Force, 2013). The Air Force accounts for 48% of the energy consumption in the DOD, and 81% of that consumption are attributed to aviation fuel. Increasing fuels prices have a significant effect on the Air Force's operation budget. For every $10 increase in a barrel of oil the Air Force has to spend another $600 million in fuel costs annually (USAF Directorate of Strategic Planning, 2011). According the Energy Strategic Plan, a reduction in energy consumption is the best action the Air Force could take to improve energy security (United States Air Force, 2013). Along with

Table 1: Summary of the Intent and Expected Outcomes of the Four Energy Priorities

AIR FORCE ENERGY STRATEGIC PLAN		
PRIORITY	**INTENT**	**EXPECTED OUTCOME**
Improve Resiliency	↗ Identify vulnerabilities to energy and water supplies, such as physical and cyber attacks or natural disasters ↗ Mitigate impacts from disruptions in energy supplies to critical assets, installations, and priority missions	↗ Improved responsiveness to disruptions to energy and water supplies ↗ Increased ability to quickly resume normal operations and mitigate impact to the mission ↗ Prioritized response plans and solutions to mitigate risk from the tail (logistics supply chain) to the tooth (energy demand in operations)
Reduce Demand	↗ Increase energy efficiency and operational efficiency for Air Force systems and processes without losing mission capabilities	↗ Decreased amount of energy required by Air Force systems and operations ↗ Increased flexibility, range, and endurance in all operations
Assure Supply	↗ Integrate platform-compatible alternative sources of energy ↗ Diversify drop-in sources of energy ↗ Increase access to reliable and uninterrupted energy supplies	↗ Access to backup energy resources and supply chains based on asset and mission priorities ↗ Increased flexibility in all operations ↗ Increased ability to sustain mission
Foster an Energy Aware Culture	↗ Integrate communication efforts using training and education opportunities to increase awareness of energy impacts to mission ↗ Ensure the acquisition process reflects energy as a mission enabler	↗ Increased understanding and awareness of energy and its impacts to the mission ↗ Reduced energy demand through more efficient uses of energy resources ↗ Increased ability to integrate energy considerations in planning activities and other decisions

Figure 1: Air Force Energy Priorities (United States Air Force, 2013)

increasing energy security, reduced demand of energy also lowers the Air Force's operational budget. In order to reduce demand the Air Force must evaluate and prioritize new fuel saving operational techniques including modifying existing operations (United States Air Force, 2013).

Alaska's Strategic Location

In 1935 while briefing the House Committee on Military Affairs, General Billy Mitchell said, "I believe that, in the future, whoever holds Alaska will hold the world...I think it is the most important strategic place in the world.” (Gedney, 1986). Although this statement was made almost 80 years ago there is significant merit in Mitchell’s foresight. Alaska is uniquely situated in North America since it is US soil that borders the Arctic region, but it does not share a geographic boarder with the lower 48 states. Alaska’s location is also unique because it much closer to many major international cities than a majority of metropolitan centers in CONUS.

In his 2008 Air Force Magazine article Marc Schanz writes, “Due to Alaska’s location, a C-17 is now a day closer to most destinations across the Pacific—and only eight hours from Germany over the North Pole” (Schanz, 2008). For years Anchorage has served as an ideal fuel stop for aircraft transiting to and from the Pacific. Its location reduces the distance and time to many locations in the Pacific and North America especially before the invention of modern aircraft that could traverse long distances across the Pacific without a fuel stop.

Alaska is not only a strategic location because of its vast airspace and reduced distance to locations in the Pacific but Alaska is a state with vast natural resources including rare earth elements and access to the increasing navigable Arctic shipping lanes (Skya & Ashok, 2014). Due to polar ice melt there has been an increase in maritime activity in the Artic (White House, 2013). The topic has become important enough for the President to create the 2013 National Strategy for the Arctic Region. Within the strategy, the President has laid out the nation’s central interest in the Arctic region which includes, “providing for the security of the United States; protecting the free flow of resources and commerce; protecting the environment; addressing the needs of indigenous communities; and enabling scientific research” (White House, 2013).

In response to the National Strategy for the Arctic Region the Department of Defense (DOD) produced the military Arctic Strategy in 2013. The Central Intelligence Agency (CIA) World Fact Book Arctic Region Map is shown in Figure 2. Within the Department of Defense Arctic Strategy the DOD lays out two main supporting objectives: 1. ensure security, support safety, and promote defense cooperation and 2. prepare for a wide range of challenges and contingencies (Department of Defense, 2013). The DOD also states that the national security objectives that the department must focus on are “missile defense and early warning; deployment of sea and air systems for strategic sealift, strategic deterrence, maritime presence, and maritime security operations; and ensuring freedom of the seas” (Department of Defense, 2013). Freedom of navigation and overflight within the Arctic region is included in the DOD’s description of preserving freedom of the seas (Department of Defense, 2013).

Figure 2: Arctic Region Map (Central Intelligence Agency, 2013)

Channel and Lilly Pad Operations

Channel missions are a category of airlift missions that provide sustainment to validated locations. There are two types of channel missions either distribution or contingency. The distribution missions are on a regularly scheduled basis and the contingency missions are on an as needed basis (Joint Chiefs of Staff, 2013). Channels can be requested through USTRANSCOM by the CCDRs in order to sustain forces within their theater. If the cargo is time sensitive then a contingency channel mission would be requested (Joint Chiefs of Staff, 2013).

The AMC Air Channel Sequence Listing is a document that AMC produces each fiscal year in order to list all of the validated channel locations, routes and associated rates. The locations are listed by the geographic AOR that they support (618 AOC (TACC)/XOGD, 2013). The channel listing is also broken down into cargo, passenger, mixed, and aeromedical variants. Currently there are 112 validated channel missions. Each channel mission is validated in both directions except for aeromedical which are considered one-way missions (618 AOC (TACC)/XOGD, 2013).

Long distances, crew requirements, or mission limitations may require an intermediate stop for certain missions. If an intermediate stop is required for a mission the mission will be referred to as a stage or lily pad operation (Joint Chiefs of Staff, 2013). An illustration of lily pad operations is represented by Figure 3.

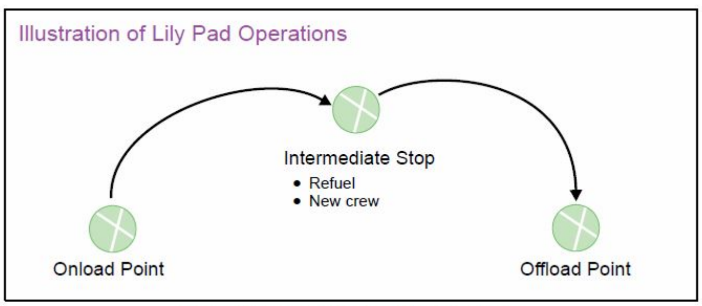


Figure IV-2. Illustration of Lily Pad Operations

Figure 3: Illustration of Lily Pad Operations (Joint Chiefs of Staff, 2013)

The final leg of the mission can terminate at the final destination or at a theater hub (Department of the Air Force, 2013).

En Route Locations

The Global Air Mobility Support System (GAMSS) is a network of permanent or deployed en route support locations that facilitate the movement of information, cargo and passengers. Personnel that fall within GAMSS deploy as part of the global reach laydown strategy. The amount of forces required to support en route locations depends upon the requirement of the station and the mission it is supporting. USTRANSCOM's network of terminals at support locations is enabled by GAMSS forces (Joint Chiefs of Staff, 2013).

Polar Route Structure

When the Cold War ended in the early 1990's, a new opportunity emerged to open the aviation polar route structure. By November of 1992 the United States government along with the Russian government established the Russian/American Coordinating Group for Air Traffic Control or RACGAT. The group was established to create trans polar air routes, mainly between North America and China, Japan and other Southeast Asia nations. Another priority was to modernize the air traffic control services along these routes (Avionics Magazine, 2002). Officials from Canada, North Korea, China, Mongolia, South Korea, the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA) attended the RACGAT meetings. It wasn't until 1995 that the establishment of the polar route structure was proposed and three more years before the Russian government gave the right to open the first four polar routes (Avionics Magazine, 2002).

The first polar routes were designated as Polar 1, 2, 3, and 4 (Figure 4). Initially the routes were considered "demonstration" routes and could be flown as non-revenue flights. Cathay Pacific seized the opportunity to fly the first cross polar route in 1998 quickly followed by Northwest Airlines and United Airlines in 1999 (Avionics Magazine, 2002). The July 1998 Cathay Pacific flight utilized a Boeing 747-400 which departed New York and landed at the "new" Hong Kong International Airport. The flight demonstrated the use of the newly minted Polar Route 2 which entered Russian airspace at point DEVID at 89N latitude.

Figure 4: Polar Routes (Arctic Portal, 2014)

Since that time the airlines have consistently utilized the polar routes to reduce distance and save fuel. An example of the amount of time savings that the airlines have been gaining is demonstrated in Figure 5. In March of 2006, a United Airline route from Chicago to Hong Kong saved 2 hours and 46 minutes by using polar route 3 compared to traditional routing. Although the polar routes can save the airline industry time and money, there are certain factors that can limit its use such as volcanic activity, unstable solar activity, solar radiation and fuel freezing potential (Stills, 2008).

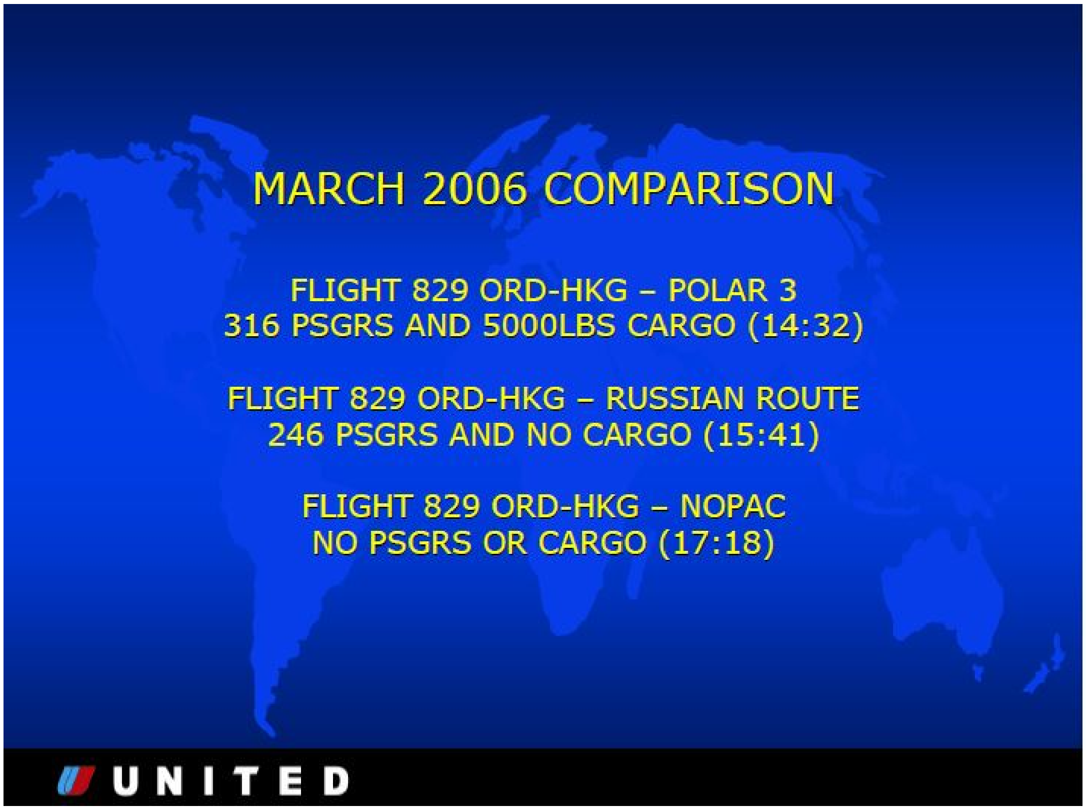


Figure 5: Polar Route Time Comparison (Stills, 2008)

The Cross Polar Working Group (CPWG), formed in 2006, is a bi-lateral, international body, which meets bi-annually to discuss polar routing issues. The CPWG consists of representatives from Russia, Canada, Iceland, the US, and other organizations such as IATA and the International Business Aviation Council (IBAC). Their discussions are documented by the Federal Aviation Administration. They focus on improving air traffic services (ATS) for aircraft that are transiting the polar region (Federal Aviation Administration, 2014).

The Air Force has used polar routing on a limited basis mainly for moving personnel and for crew and aircraft rotations. USTRANSCOM utilized the polar route structure from 2010 to 2014 and have saved and estimated $45.8 million in fuel and TDY costs (Jiron, 2014). The last polar route was flown in February 2014 due to the eventual shutdown of Manas Transit Center (UFAM). In 2011 AMC did a basic cost analysis of using various West coast cargo hubs to determine if there would be any cost savings by hauling cargo via polar routes. It was determined PAED would be the best origin option to airlift cargo and the C-5M would be the optimal aircraft (AMC/A9, 2011). The AMC has not extensively used polar routing for cargo operations because a letter of agreement with the Russian government that limits the cargo that is allowed to be carried on polar routes. The other major factor that prevents more extensive usage of polar routing is that the Kyrgyz government failed to renew the US lease of the Manas Transit Center (Nichol, 2013).

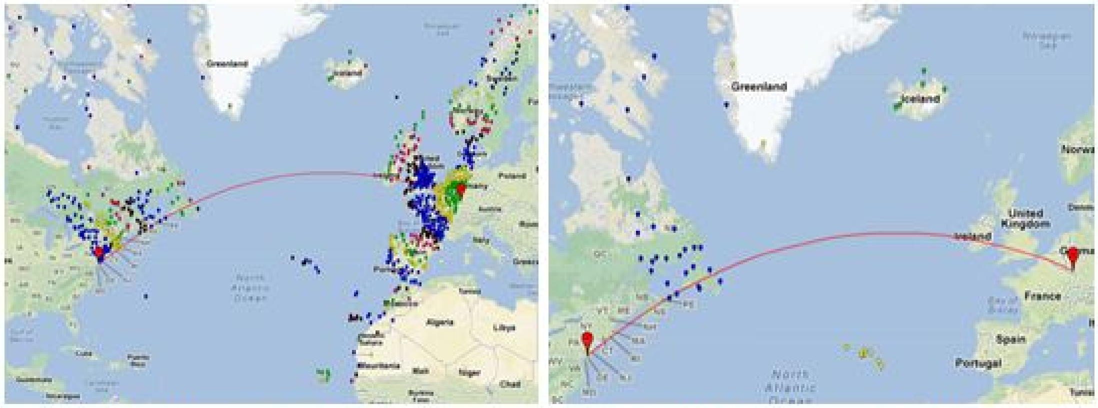
AFIT Route Analyzer Model

The AFIT Route Analyzer was created by AFIT PhD student Lt Col Adam Reiman. The model was created to aid in strategic airlift planning using web based JAVA software. The analyzer uses an origin and destination airfield ICAO to cycle through routing alternatives (Reiman, 2013).

The interface is divided into three columns including airfield filters, country filters and requirement parameters. The airfield filters can remove airfields if they do not meet certain criteria such as runway length, critical field gross weight, or minimum pavement strength based on the selected aircraft type. The country filters remove Russia, China, Venezuela, and Iran from consideration. The requirement parameters can limit the number of primary airfields, secondary airfields and maximum number of legs (Reiman, 2013).

Primary airfields use the lens or eye shape (Figure 6) to determine where the possible secondary airfields can be located. Minimum cutoff distances can be input to limit the number of secondary airfields in consideration (Figure 7). The final input section is the planning assumptions. The planning assumptions include planned payload, augmented crew, transloading, and staging. The inputs of the planning factors are used to find optimal routings (Reiman, 2013).

Figure 6: Eye Shape for Primary Airfields (Reiman, 2013)



No minimum cutoff distance 700 NM minimum cutoff distance

Figure 7: Route Analyzer Secondary Airfields (Reiman, 2013)

If the augmented check box is checked then the Route Analyzer will use an augmented flight duty period when calculating the time requirements for the route. If the box is left unchecked then a normal flight duty period will be used. When the staging box is checked the program will use ground times as described in AFPAM 10-1403 Air Mobility Planning factors. The en route locations are used for refueling purposes and it is reflected in the calculated ground time. If staging is used in the model then a crew rest period is not added at the end of the flight duty period. When staging is not used then a crew rest period is required at the end of the flight duty period (Reiman, 2013).

The results of the input parameters are measured in the output fields. The output fields include the route, total distance, maximum payload no transloading, cycle time no transloading, maximum payload cargo throughput, maximum payload fuel efficiency, planned payload cargo throughput, planned payload fuel efficiency, and details. The user has the ability to view a graphical representation of the route as well as drill down into further details about the route to include the status of the airfield and weather at the field (Reiman, 2013).

The maximum payload fuel efficiency output is calculated by dividing the cargo throughput per day by the fuel consumed per day based on the maximum payload (Reiman, 2013). This output is useful in determining fuel efficiency when the planned payload is not determined. The maximum function of this output will load the aircraft with as much payload as possible for the designated route.

P-Center Model

The P-center model is a heuristic method that is based on facility location theory that is often used to optimize location of facilities such as hospitals or fire stations (Jia, Ordonez, & Dessouky, 2007). One example is the Weber problem which is one form of a facility location problem. The Weber problem's objective is to find a location for a new facility which minimizes the transportation cost which can be described by the weighted sum of distances from demand points (Drezner & Drezner, 2011). The basic concept of the Weber problem is used in P-center problems such as the one used by the model for this project.

For this model instead of minimizing the distance which is the typical method of location theory the model maximizes the maximum payload fuel efficiency rating produced for each route by the AFIT route analyzer. By maximizing the fuel efficiency rating it is, in effect, identifying the most efficient location based on the maximum amount of cargo for the amount of fuel. Instead of minimizing distance, the model maximizes efficiency.

The model was created in Microsoft Excel and uses the "max" function formula to find the largest maximum payload fuel efficiency rating for each origin/destination pair. The model can compare all origin locations at once or it can be used to compare any number of the 6 origins against each other. Once the largest maximum payload fuel efficiency for a particular origin/destination pair is established the model then multiplies that number by a frequency multiplier. The frequency is a reflection of how many times that airfield has been used for channel missions over a three year period. Simply put, it is a number input into a cell that is multiplied by the maximum payload fuel efficiency rating.

Summary

Due to a declining military spending the Air Force is looking for ways to decrease operational spending and increasing fuel efficiency is a significant part of that endeavor. One way to increase efficiencies is to find strategic airlift locations that can service many destinations simultaneously in order to quickly support CCDRs requirements. The polar route structure has been successful for the commercial airline industry in reducing distance and time flown between origin and destination and is a viable method of reducing the strategic airlift fuel consumption. Since Alaska is in a unique position to best utilize the polar routes due to its close proximity, further analysis of its strategic geographic location is warranted. Route analysis modeling coupled with P-center location theory modeling provide a valuable and unique method to determine if utilization of Alaska’s location does increase strategic airlift fuel efficiency in comparison to other US bases.

III. Methodology

Chapter Overview

This chapter discusses the comparative fuel efficiency analysis methodology that was used in accomplishing the research.

Test Subjects

Six US Active Duty Air Force C-17A bases, Joint Base McGuire-Dix-Lakehurst (KWRI), Dover Air Force Base (KDOV), Joint Base Charleston (KCHS), Travis Air Force Base (KSUU), Joint Base Lewis-McChord (KTCM), and Joint Base Elmendorf-Richardson (PAED), were evaluated in this research. The research is focused on the highest maximum payload fuel efficiency rating for each location of origin to 27 different validated channel locations.

Assumptions

There are several assumptions used in this research:

1. The data that the Route Analyzer provides is correct and most fuel efficient.
2. Aircraft would be flown consistent with their technical data and in a similar profile as the Route Analyzer sets forth.
3. Refueling capabilities would be available at the en route locations identified by the Route Analyzer database.
4. The USAF would be able to obtain the appropriate diplomatic clearance to fly the routes as prescribed by the Route Analyzer.

5. For flights that would cross into the polar region there would be valid overflight agreements with the required states in order for mission accomplishment.

6. Weather is sufficient for mission accomplishment.

7. The aerial ports at the points of origin have the capacity to process cargo as required by the mission.

8. There is sufficient infrastructure available to position cargo via land or sea based means to any of the 6 bases studied in this research.

Process

Six currently used Active Duty C-17A bases were selected as test subjects to determine which base provides the most fuel efficient origin in order to service EUCOM, PACOM, and CENTCOM simultaneously. The researcher chose Joint Base McGuire-Dix-Lakehurst, Dover Air Force Base, Joint Base Charleston, Travis Air Force Base, Joint Base Lewis-McChord, and Joint Base Elmendorf-Richardson as the test subject bases. These bases were selected since they currently operate North American Active Duty C-17A units and because they have capable aerial ports that can accept cargo from land or sea based modes of transportation.

Once the test subject origin points were selected they were matched to 27 different validated channel locations throughout EUCOM, CENTCOM, and PACOM. The only location outside of EUCOM, CENTCOM, and PACOM that was selected was Ambouli, Djibouti (HDAM) which falls in the AOR of Africa Command (AFRICOM). This location was added to the location list because it is the most frequently used Africa channel location and a majority of the flights originate from either EUCOM or

CENTCOM that terminate in Djibouti. One location that does not appear on the list of validated channel locations is Mihail Kogălniceanu International Airport (LRCK). LRCK has taken over as the main transit center for inbound and outbound Afghanistan missions. The researcher deemed it irrelevant to this research. The 27 destinations selected are listed in Table 1.

Table 1: Destination Locations

Identifier	Location	AOR
BGTL	THULE AB, GREENLAND	EUCOM
EGUN	MILDENHAL RAF, GB	EUCOM
ETAR	RAMSTEIN AB, GERMANY	EUCOM
FJDG	DIEGO GARCIA, BIOT	PACOM
HDAM	AMBOULI, DJIBOUTI	AFRICOM*
HECA	CAIRO, EGYPT	EUCOM
LERT	ROTA NAS, SPAIN	EUCOM
LICZ	SIGONELLA NAS, SICILY	EUCOM
LIPA	AVIANO AB, ITALY	EUCOM
LRCK	MIHAIL KOGALNICEANU, RO	EUCOM
LTAG	INCIRLIK AB, TU	EUCOM
OAIX	BAGRAM AB, AFG	CENTCOM
OAKN	KANDAHAR, AFG	CENTCOM
OAMS	MAZAR I SHARIF, AFG	CENTCOM
OAZI	BASTION, AFGHANISTAN	CENTCOM
OBBI	BAHRAIN IAP, BAHRAIN	CENTCOM
OKBK	KUWAIT CITY KWI	CENTCOM
OTBH	AL UDEID AB UATAR	CENTCOM
PGUA	ANDERSEN AFB, GUAM	PACOM
PHIK	HICKAM AFB, HI	PACOM
PWAK	WAKE ISLAND AAF	PACOM
RJTY	YOKOTA AB JAPAN	PACOM
RKSO	OSAN AB, SOUTH KOREA	PACOM
RODN	KADENA AB, JAPAN	PACOM
RPMZ	ZAMBOANGA, PHILIPPINES	PACOM
WSAP	PAYA LEBAR SINGAPORE	PACOM
YSRI	RICHMOND, AUSTRAILA	PACOM

Each of the 6 points of origin was then paired up with the 27 points of destinations. Then each origin and destination pair was run through the AFIT Route Analyzer to determine what the most fuel efficient route for each origin destination pair. Within the Route Analyzer the route was limited by one en route stop. Only C-17A data was used in the model. The routes were run through the analyzer using the stipulations that they were flown using augmented crews in conjunction with staging operations. All routes used the identical criteria when the origin and destination were input into the analyzer. The Route Analyzer determined the most fuel efficient route for each origin/destination pair however; the program prevented the en route stop from being inside the countries of Venezuela, China, Russian and Iran. The Route Analyzer computed the top 200 most fuel efficient routes which were then sorted by the maximum payload fuel efficiency rating as shown in Figure 8.

The resultant route that had the largest maximum payload fuel efficiency rating (unitless number) was added to the maximum payload fuel efficiency rating matrix. The only deviation from the largest maximum payload fuel efficiency rating occurred when a known USAF en route or US military installation en route location was within 100 nautical miles of the suggested en route stop and the delta of the maximum payload fuel efficiency rating was less than .01, then the known en route stop was used. For example, if a route traveled through Europe and an en route location within Spain was rated with the largest maximum payload fuel efficiency rating, but the second optimal route included a stop at Rota NAS, Spain and the total distance did not deviate more than 100 nautical miles or change the maximum payload fuel efficiency rating by more than .01

then Rota NAS would have been the en route stop listed, thus becoming the most efficient route.

Routing Summary										
Total Routes	Primary Aflds	Secondary Aflds	Route 1		Route 2		Compare			
8	7	0								
Top Route	Total Distance	Max Payload No Trans	Cycle Time No Trans	Max Payload Cargo Thru	Max Payload Fuel Eff	Plan Payload Cargo Thru	Plan Payload Fuel Eff	Details	Compare	
KDOV-CYYT-EGUN	3,144.65	141.96	26.08	130.65	0.44	78.23	0.26	route	rte1 rte2	

Routes									
Route	Total Distance	Max Payload No Trans	Cycle Time No Trans	Max Payload Cargo Thru	Max Payload Fuel Efficiency	Plan Payload Cargo Thru	Plan Payload Fuel Efficiency	Details	Compare
KDOV-EGUN	3,134.35	97.49	21.07	111.07	0.33	96.84	0.29	route	rte1 rte2
Route	Total Distance	Max Payload No Trans	Cycle Time No Trans	Max Payload Cargo Thru	Max Payload Fuel Efficiency	Plan Payload Cargo Thru	Plan Payload Fuel Efficiency	Details	Compare
KDOV-CYYT-EGUN	3,144.65	141.96	26.08	130.65	0.44	78.23	0.26	route	rte1 rte2
KDOV-CYQX-EGUN	3,134.69	140.80	26.04	129.78	0.44	78.35	0.26	route	rte1 rte2
KDOV-CYJT-EGUN	3,135.03	134.50	26.06	123.87	0.42	78.28	0.27	route	rte1 rte2
KDOV-CYYR-EGUN	3,201.11	137.14	26.34	124.96	0.42	77.45	0.26	route	rte1 rte2
KDOV-CYFB-EGUN	3,681.32	135.77	28.44	114.59	0.36	71.74	0.23	route	rte1 rte2
KDOV-LPLA-EGUN	3,643.30	133.46	28.27	113.29	0.36	72.15	0.23	route	rte1 rte2
KDOV-LPPD-EGUN	3,722.13	130.12	28.63	109.09	0.35	71.26	0.23	route	rte1 rte2

Figure 8: Route Analyzer Data Example

All 162 combinations of origins and destinations were run through the AFIT Route Analyzer and a matrix was created which designated the maximum payload fuel efficiency rating for the optimal route. The route maximum payload fuel efficiency rating matrix (Table 2) shows the highest maximum payload fuel efficiency rating on the prescribed route. The top column is the 6 points of origin and rows along the left side of the matrix correspond to the 27 destinations.

Table 2: Maximum Payload Fuel Efficiency Rating Matrix

Column1	KDOV	KWRI	KCHS	PAED	KTCM	KSUU
BGTL	0.64	0.62	0.55	0.84	0.63	0.58
EGUN	0.44	0.45	0.39	0.32	0.33	0.28
ETAR	0.37	0.38	0.33	0.27	0.28	0.26
FJDG	0.08	0.08	0.07	0.1	0.07	0.05
HDAM	0.16	0.17	0.15	0.15	0.12	0.09
HECA	0.23	0.24	0.2	0.21	0.17	0.13
LERT	0.41	0.42	0.37	0.23	0.27	0.24
LICZ	0.32	0.33	0.27	0.22	0.19	0.18
LIPA	0.33	0.34	0.29	0.24	0.24	0.22
LRCK	0.29	0.3	0.25	0.24	0.19	0.17
LTAG	0.25	0.25	0.21	0.22	0.18	0.14
OAIX	0.17	0.17	0.15	0.2	0.14	0.12
OAKN	0.17	0.17	0.15	0.2	0.13	0.11
OAMS	0.18	0.19	0.16	0.21	0.14	0.12
OAZI	0.17	0.18	0.15	0.2	0.13	0.12
OBBI	0.19	0.19	0.16	0.2	0.13	0.12
OKBK	0.2	0.21	0.17	0.2	0.15	0.12
OTBH	0.18	0.19	0.16	0.19	0.13	0.12
PGUA	0.1	0.1	0.1	0.29	0.23	0.21
PHIK	0.32	0.32	0.33	0.53	0.57	0.65
PWAK	0.17	0.17	0.17	0.41	0.3	0.34
RJTY	0.18	0.18	0.17	0.47	0.3	0.25
RKSO	0.15	0.15	0.15	0.39	0.28	0.24
RODN	0.11	0.11	0.11	0.32	0.24	0.22
RPMZ	0.08	0.08	0.07	0.25	0.13	0.12
WSAP	0.05	0.05	X	0.19	0.12	0.1
YSRI	0.06	0.06	0.06	0.15	0.11	0.11

After the highest maximum payload fuel efficiency rating was determined for each origin/destination pair, the data was then input into a P-center location model used to maximize the maximum payload fuel efficiency rating. The model matches each origin to each destination and selects the largest maximum payload fuel efficiency rating for the pair. For example, of all 6 origins PAED was rated the highest for the destination of BGTL with a maximum payload fuel efficiency rating of .84. When all the origins were selected in the P-center model the origin with the largest maximum payload fuel efficiency rating for each destination is identified.

The P-center model then multiplies the largest maximum payload fuel efficiency rating of each destination by the frequency of channel missions passing through each destination. The channel mission number is the frequency of channel missions landing at a location for the last 3 years (2011-2013). This data was obtained from AMC/A9 and pulled from the Global Decision Support System 2 (GDSS2). Using the BGTL example, the P-center model determines that the origin of PAED has the largest maximum payload fuel efficiency rating of .84 and then it is multiplied by the frequency of channel missions that have landed at BGTL over a three year period or 420 times. The result is a unitless number that represents a maximum payload fuel efficiency rating with a frequency multiplier. In this example the frequency based maximum payload fuel efficiency rating for PAED – BGTL is 352.8 (.84 * 420 = 352.8). The larger the number the more efficient the route based on frequency. Once all the frequency based maximum payload fuel efficiency ratings are determined for each origin/destination pair, the P-center model calculates the largest possible frequency based maximum payload fuel efficiency rating when all the origins are input. For each destination, the origin gaining the largest maximum payload fuel efficiency rating is recorded and counted. The origin that had the largest maximum payload fuel efficiency rating for the greatest amount of destinations is determined to be the most ideal location to quickly support airlift operations to the AORs of PACOM, CENTCOM, and EUCOM simultaneously in the most fuel efficient manner.

Summary

The methodology for this research includes the use of two different models. First each origin and destination pair is run through the AFIT Route Analyzer model to determine the most efficient route and to calculate the maximum payload fuel efficiency rating for each origin/destination pair. Once the maximum payload fuel efficiency rating data is compiled, a P-center model is used to determine a frequency based maximum payload fuel efficiency rating. The P-center model used for location theory provided the highest rated route for each origin destination pair and finally the origin that had the overall greatest frequency based maximum payload fuel efficiency rating for each destination. The two distinct models working in conjunction provide useful and accurate data to not only determine the best routes, but also the best origin location based on the research criteria.

IV. Analysis and Results

Chapter Overview

This research analyzes data from two different models. First the route with the largest maximum payload fuel efficiency rating is determined for each origin/destination pair by inputting 162 combinations of origin/destination pairs into the AFIT Route Analyzer. The data is then input into a matrix and run through a P-center model to determine the largest frequency based maximum payload fuel efficiency rating for each origin/destination pair. Finally the location that can best service airlift operations to the AORs of PACOM, CENTCOM, and EUCOM simultaneously in the most fuel efficient manner is identified.

Results of Modeling

The results and analysis of the two models used in this research are provided in this section.

Results of AFIT Route Analyzer model

Once the origin and destination locations are determined the origin and destination pairs are run through the AFIT Route Analyzer. The Route Analyzer calculates the most efficient route with one en route stop based on the largest maximum payload fuel efficiency rating. The results for each origin are provided in Table 3 through Table 8.

Table 3: AFIT Route Analyzer Results for KDOV

ORIGIN	STOP	DESTINATION	Total Distance	Max Payload Fuel Efficiency
KDOV	CYYR	BGTL	2,462.56	0.64
KDOV	CYYT	EGUN	3,144.65	0.44
KDOV	CYYT	ETAR	3,455.29	0.37
KDOV	LIBG	FJDG	8,240.47	0.08
KDOV	LERT	HDAM	6,264.36	0.16
KDOV	EINN	HECA	5,018.57	0.23
KDOV	CYYT	LERT	3,249.03	0.41
KDOV	LPLA	LICZ	4,211.23	0.32
KDOV	LPLA	LIPA	4,034.44	0.33
KDOV	BIKF	LRCK	4,441.05	0.29
KDOV	BIKF	LTAG	4,983.73	0.25
KDOV	EGUN	OAIX	6,179.11	0.17
KDOV	EGUN	OAKN	6,195.49	0.17
KDOV	EGPH	OAMS	5,949.45	0.18
KDOV	EGUN	OAZI	6,121.08	0.17
KDOV	EGPH	OBBI	5,867.06	0.19
KDOV	EINN	OKBK	5,644.35	0.2
KDOV	EGPK	OTBH	5,942.74	0.18
KDOV	PAED	PGUA	6,941.65	0.1
KDOV	KSUU	PHIK	4,275.14	0.32
KDOV	PAED	PWAK	6,068.20	0.17
KDOV	PAED	RJTY	5,978.46	0.18
KDOV	PAEI	RKSO	6,188.19	0.15
KDOV	PAED	RODN	6,778.01	0.11
KDOV	PASY	RPMZ	7,963.12	0.08
KDOV	PASY	WSAP	8,853.06	0.05
KDOV	PHNG	YSRI	8,678.61	0.06

Table 4: AFIT Route Analyzer Results for KWRI

ORIGIN	STOP	DESTINATION	Total Distance	Max Payload Fuel Efficiency
KWRI	X	BGTL	2,201.25	0.62
KWRI	CYYT	EGUN	3,081.38	0.45
KWRI	CYYT	ETAR	3,392.01	0.38
KWRI	LIBG	FJDG	8,176.97	0.08
KWRI	LERT	HDAM	6,207.98	0.17
KWRI	EINN	HECA	4,953.49	0.24
KWRI	CYYT	LERT	3,185.76	0.42
KWRI	LPLA	LICZ	4,158.65	0.33
KWRI	LPLA	LIPA	3,981.87	0.34
KWRI	BIKF	LRCK	4,374.35	0.3
KWRI	BIKF	LTAG	4,917.04	0.25
KWRI	EGUN	OAIX	6,113.67	0.17
KWRI	EGUN	OAKN	6,130.05	0.17
KWRI	EGPH	OAMS	5,883.26	0.19
KWRI	EGUN	OAZI	6,055.64	0.18
KWRI	EGPH	OBBI	5,800.87	0.19
KWRI	EINN	OKBK	5,579.28	0.21
KWRI	EGPH	OTBH	5,877.95	0.19
KWRI	PAED	PGUA	6,924.74	0.1
KWRI	KSUU	PHIK	4,302.37	0.32
KWRI	PAED	PWAK	6,051.30	0.17
KWRI	PAED	RJTY	5,961.56	0.18
KWRI	PAED	RKSO	6,248.52	0.15
KWRI	PAED	RODN	6,761.10	0.11
KWRI	PASY	RPMZ	7,945.14	0.08
KWRI	PASY	WSAP	8,835.09	0.05
KWRI	PHNG	YSRI	8,706.48	0.06

Table 5: AFIT Route Analyzer Results for KCHS

ORIGIN	STOP	DESTINATION	Total Distance	Max Payload Fuel Efficiency
KCHS	CYYB	BGTL	2,641.93	0.55
KCHS	CYYT	EGUN	3,553.51	0.39
KCHS	CYYT	ETAR	3,864.14	0.33
KCHS	LHBP	FJDG	8,653.43	0.07
KCHS	LEST	HDAM	6,617.04	0.15
KCHS	LPLA	HECA	5,470.65	0.2
KCHS	CYYT	LERT	3,657.89	0.37
KCHS	LPLA	LICZ	4,545.61	0.27
KCHS	CYYT	LIPA	4,132.09	0.29
KCHS	LPLA	LRCK	5,048.77	0.25
KCHS	BIKF	LTAG	5,418.16	0.21
KCHS	EGPF	OAIX	6,521.26	0.15
KCHS	EGPF	OAKN	6,560.09	0.15
KCHS	EINN	OAMS	6,443.43	0.16
KCHS	EGPF	OAZI	6,489.40	0.15
KCHS	EINN	OBBI	6,285.81	0.16
KCHS	EINN	OKBK	6,059.86	0.17
KCHS	EINN	OTBH	6,361.57	0.16
KCHS	PAED	PGUA	7,110.11	0.1
KCHS	KSUU	PHIK	4,173.68	0.33
KCHS	PAED	PWAK	6,236.67	0.17
KCHS	PAED	RJTY	6,146.93	0.17
KCHS	PAED	RKSO	6,433.89	0.15
KCHS	PAED	RODN	6,946.47	0.11
KCHS	PASY	RPMZ	8,124.77	0.07
KCHS	X	WSAP	X	X
KCHS	PHNG	YSRI	8,541.86	0.06

Table 6: AFIT Route Analyzer Results for PAED

ORIGIN	STOP	DESTINATION	Total Distance	Max Payload Fuel Efficiency
PAED	X	BGTL	1,780.71	0.84
PAED	CYFB	EGUN	4,293.32	0.32
PAED	CYFB	ETAR	4,605.31	0.27
PAED	UAKK	FJDG	7,253.17	0.1
PAED	EFKI	HDAM	6,509.16	0.15
PAED	ENNA	HECA	5,339.90	0.21
PAED	BIKF	LERT	4,678.35	0.23
PAED	ENNA	LICZ	4,920.40	0.22
PAED	ENNA	LIPA	4,422.46	0.24
PAED	ENNA	LRCK	4,480.21	0.24
PAED	ENNA	LTAG	4,946.33	0.22
PAED	ENNA	OAIX	5,479.96	0.2
PAED	ENNA	OAKN	5,616.22	0.2
PAED	ENNA	OAMS	5,345.77	0.21
PAED	ENNA	OAZI	5,570.04	0.2
PAED	ENNA	OBBI	5,708.00	0.2
PAED	ENNA	OKBK	5,506.14	0.2
PAED	ENNA	OTBH	5,782.91	0.19
PAED	RJCM	PGUA	4,314.36	0.29
PAED	X	PHIK	2,418.88	0.53
PAED	PASY	PWAK	3,303.54	0.41
PAED	PASY	RJTY	3,055.57	0.47
PAED	PASY	RKSO	3,437.09	0.39
PAED	RJCM	RODN	3,819.46	0.32
PAED	RJCM	RPMZ	4,999.14	0.25
PAED	RJSN	WSAP	5,845.83	0.19
PAED	PWAK	YSRI	6,397.69	0.15

Significant Results:

1. Routes highlighted in yellow indicate polar route usage.

Table 7: AFIT Route Analyzer Results for KTCM

ORIGIN	STOP	DESTINATION	Total Distance	Max Payload Fuel Efficiency
KTCM	X	BGTL	2,182.03	0.63
KTCM	CYFB	EGUN	4,194.12	0.33
KTCM	CYFB	ETAR	4,506.12	0.28
KTCM	RJOO	FJDG	8,725.71	0.07
KTCM	ENNA	HDAM	7,216.11	0.12
KTCM	BIKF	HECA	6,030.45	0.17
KTCM	CYYR	LERT	4,782.25	0.27
KTCM	CYYT	LICZ	5,710.05	0.19
KTCM	CYFB	LIPA	4,792.11	0.24
KTCM	BIKF	LRCK	5,236.70	0.19
KTCM	BIFK	LTAG	5,779.39	0.18
KTCM	ENNA	OAIX	6,188.38	0.14
KTCM	ENNA	OAKN	6,324.64	0.13
KTCM	ENNA	OAMS	6,054.20	0.14
KTCM	ENNA	OAZI	6,278.46	0.13
KTCM	ENNA	OBBI	6,416.42	0.13
KTCM	BIKF	OKBK	6,506.16	0.15
KTCM	ENNA	OTBH	6,491.33	0.13
KTCM	PASY	PGUA	5,128.43	0.23
KTCM	X	PHIK	2,311.21	0.57
KTCM	PHNG	PWAK	4,306.22	0.3
KTCM	PASY	RJTY	4,185.81	0.3
KTCM	PASY	RKSO	4,567.33	0.28
KTCM	PASY	RODN	5,001.90	0.24
KTCM	PASY	RPMZ	6,135.12	0.13
KTCM	RJCM	WSAP	7,021.43	0.12
KTCM	PWAK	YSRI	7,081.87	0.11

Significant Results:

1. Routes highlighted in yellow indicate polar route usage.

Table 8: AFIT Route Analyzer Results for KSUU

ORIGIN	STOP	DESTINATION	Total Distance	Max Payload Fuel Efficiency
KSUU	CYMM	BGTL	2,685.83	0.58
KSUU	CYFB	EGUN	4,606.37	0.28
KSUU	CYFB	ETAR	4,918.37	0.26
KSUU	RJTY	FJDG	9,054.94	0.05
KSUU	ENAN	HDAM	7,716.02	0.09
KSUU	BIKF	HECA	6,472.06	0.13
KSUU	CYYR	LERT	5,082.68	0.24
KSUU	CYYT	LICZ	5,964.41	0.18
KSUU	CYYR	LIPA	5,395.56	0.22
KSUU	CYFB	LRCK	5,674.35	0.17
KSUU	BIKF	LTAG	6,221.00	0.14
KSUU	BIKF	OAIX	7,207.38	0.12
KSUU	BIKF	OAKN	7,298.54	0.11
KSUU	BIKF	OAMS	7,065.39	0.12
KSUU	BIKF	OAZI	7,238.51	0.12
KSUU	BIKF	OBBI	7,171.66	0.12
KSUU	BIKF	OKBK	6,947.77	0.12
KSUU	BIKF	OTBH	7,249.67	0.12
KSUU	PASY	PGUA	5,463.69	0.21
KSUU	X	PHIK	2,116.35	0.65
KSUU	PHNG	PWAK	4,111.30	0.34
KSUU	PASY	RJTY	4,521.07	0.25
KSUU	PASY	RKSO	4,902.59	0.24
KSUU	PASY	RODN	5,337.16	0.22
KSUU	PASY	RPMZ	6,470.38	0.12
KSUU	PWAK	WSAP	7,678.42	0.1
KSUU	PWAK	YSRI	7,128.35	0.11

Significant Results:

1. Route highlighted in yellow indicates polar route usage.

Route Analyzer Data Analysis

The AFIT Route Analyzer provides numerous pieces of data to include: the en route stop, total distance, maximum payload no transload, cycle time no transload, maximum payload cargo throughput, maximum payload fuel efficiency, planned payload cargo throughput, and planned payload fuel efficiency. This research uses the maximum payload fuel efficiency rating for analysis. Within the analysis it is noted which routes are selected that crossed into the polar region. Since the total distance was calculated it is noted that it is closely correlated to the fuel efficiency rating. However, when the maximum payload fuel efficiency rating is calculated, distance is not the only factor taken into consideration. The route with the highest noted maximum payload fuel efficiency rating of .84 was from PAED to BGTL with no intermediate stops. This route had a total distance of 1,781 nautical miles. The data also shows that the one route that could not be completed with only one intermediate stop was KCHS to WSAP. The analyzer failed to provide data on this route because it could not be completed based on the C-17As range.

One of most significant elements of the data is that PAED had the largest maximum payload fuel efficiency rating to all of the destinations in CENTCOM except for OKBK. For 6 of the 7 locations in the CENTCOM AOR the origin of PAED is the most efficient. The only deviation is the destination of OKBK, in which PAED's rating of .20 is .01 lower than KWRI's rating of .21. It is also noted that the routes from PAED to the 7 CENTCOM destinations utilized polar routes on every occasion. Polar routes are utilized 14 times from PAED, 7 times from KTCM and one time from KSUU.

P-Center Model Data Analysis

After all the proposed routes from the AFIT Route Analyzer are analyzed and the maximum payload fuel efficiency rating is determined, the data is entered into a maximum payload fuel efficiency rating matrix (Table 2). The P-center model's first process is to use the matrix in order to determine which origin had the largest maximum payload fuel efficiency rating for each of the destinations. The model output provides a number that corresponds to each origin (Table 9).

Table 9: Origin Reference Numbers

Origin	Reference Number
KDOV	1
KWRI	2
KCHS	3
PAED	4
KTCM	5
KSUU	6

The P-center model selects the origin that is rated to have the largest maximum payload fuel efficiency rating from a Microsoft Excel worksheet. The Excel formula identifies the maximum number for each origin/destination pair and lists the output as a reference number referring to the origin that had the highest rating. The resultant data is listed in Table 10. This output is listed before the maximum payload fuel efficiency rating is multiplied by the location frequency multiplier.

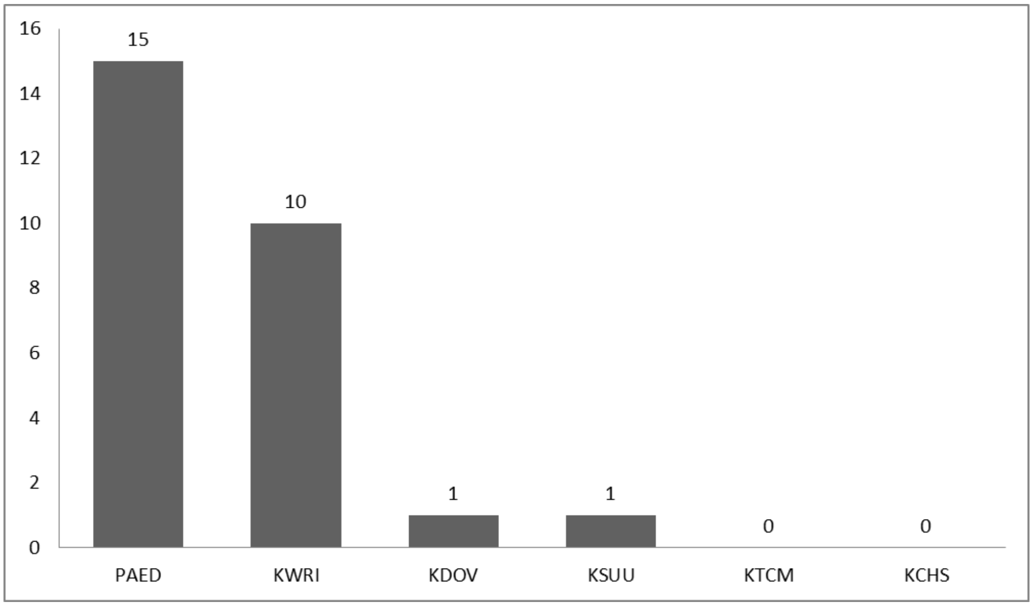
Table 10: P-Center Output Data Without Frequency Multiplier

Destination	MAX	Location	KDOV	KWRI	KCHS	PAED	KTCM	KSUU
BGTL	**0.84**	4	0.64	0.62	0.55	**0.84**	0.63	0.58
EGUN	**0.45**	2	0.44	**0.45**	0.39	0.32	0.33	0.28
ETAR	**0.38**	2	0.37	**0.38**	0.33	0.27	0.28	0.26
FJDG	**0.1**	4	0.08	0.08	0.07	**0.1**	0.07	0.05
HDAM	**0.17**	2	0.16	**0.17**	0.15	0.15	0.12	0.09
HECA	**0.24**	2	0.23	**0.24**	0.2	0.21	0.17	0.13
LERT	**0.42**	2	0.41	**0.42**	0.37	0.23	0.27	0.24
LICZ	**0.33**	2	0.32	**0.33**	0.27	0.22	0.19	0.18
LIPA	**0.34**	2	0.33	**0.34**	0.29	0.24	0.24	0.22
LRCK	**0.3**	2	0.29	**0.3**	0.25	0.24	0.19	0.17
LTAG	**0.25**	1	**0.25**	0.25	0.21	0.22	0.18	0.14
OAIX	**0.2**	4	0.17	0.17	0.15	**0.2**	0.14	0.12
OAKN	**0.2**	4	0.17	0.17	0.15	**0.2**	0.13	0.11
OAMS	**0.21**	4	0.18	0.19	0.16	**0.21**	0.14	0.12
OAZI	**0.2**	4	0.17	0.18	0.15	**0.2**	0.13	0.12
OBBI	**0.2**	4	0.19	0.19	0.16	**0.2**	0.13	0.12
OKBK	**0.21**	2	0.2	**0.21**	0.17	0.2	0.15	0.12
OTBH	**0.19**	2	0.18	**0.19**	0.16	0.19	0.13	0.12
PGUA	**0.29**	4	0.1	0.1	0.1	**0.29**	0.23	0.21
PHIK	**0.65**	6	0.32	0.32	0.33	0.53	0.57	**0.65**
PWAK	**0.41**	4	0.17	0.17	0.17	**0.41**	0.3	0.34
RJTY	**0.47**	4	0.18	0.18	0.17	**0.47**	0.3	0.25
RKSO	**0.39**	4	0.15	0.15	0.15	**0.39**	0.28	0.24
RODN	**0.32**	4	0.11	0.11	0.11	**0.32**	0.24	0.22
RPMZ	**0.25**	4	0.08	0.08	0.07	**0.25**	0.13	0.12
WSAP	**0.19**	4	0.05	0.05	0	**0.19**	0.12	0.1
YSRI	**0.15**	4	0.06	0.06	0.06	**0.15**	0.11	0.11

The data from Table 10 shows that only 4 of the 6 origin test subjects returned the largest maximum payload fuel efficiency rating for a destination location. KCHS and KTCM did not provide the largest maximum payload fuel efficiency rating for any destination, thus making those origins insignificant. The origin locations of PAED and KWRI are determined to be the most significant without the inclusion of frequency to each destination. PAED has the largest maximum payload fuel efficiency rating to

55.56% (15 of 27) of the destinations. This result is presented in the raw number format in Table 11.

Table 11: Frequency of Largest Maximum Payload Fuel Efficiency Rating from Origin to Each Destination



KWRI has the second highest number of optimal routes that have the largest maximum payload fuel efficiency rating with 10 of 27 or 37.04%. The data clearly indicates that the 2 locations of PAED and KWRI were the preferred origins by a wide margin. However, even with the data that identified the combination of PAED and KWRI to amount to 92.59% of the optimal routes, it is still important to use a frequency multiplier in order to gage if those preferred routes actually terminated at a frequently used destination.

Usage frequency of a destination is determined by examining the last 3 years of channel mission data from GDSS2. The data is sorted and limited to the 27 locations in this research. The data is also sorted in 2 categories. The first is only C-17A arrivals into that station. The second category is a count of all channel missions that transited the 27 destinations. Table 12 shows the total sorties to each destination researched over a three year period from 2011-2013.

Table 12: Location Frequency

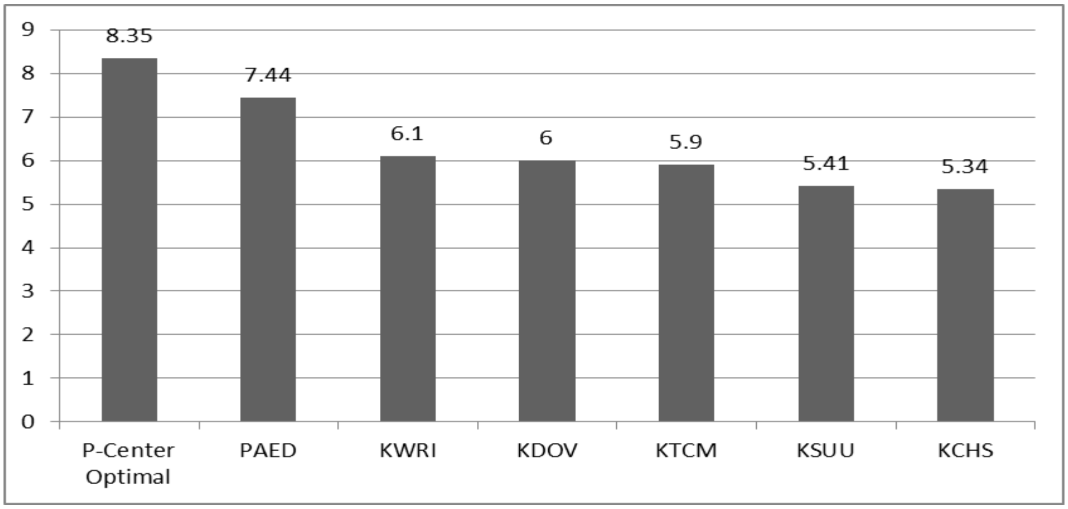
Destination	Count all MDS	C-17 Only
BGTL	420	4
EGUN	451	71
ETAR	9592	3594
FJDG	980	286
HDAM	390	51
HECA	142	3
LERT	2275	720
LICZ	302	1520
LIPA	680	18
LRCK	192	21
LTAG	5498	3021
OAIX	3317	1220
OAKN	2066	1622
OAMS	200	67
OAZI	1665	1526
OBBI	1520	270
OKBK	1597	144
OTBH	2312	878
PGUA	1039	131
PHIK	3180	656
PWAK	112	6
RJTY	2816	440
RKSO	1588	50
RODN	1429	78
RPMZ	47	0
WSAP	1073	355
YSRI	359	347

Both of the frequency categories are then multiplied by the optimal maximum payload fuel efficiency ratings for each route highlighted in yellow on Table 10. The result of multiplying the frequency by the maximum payload fuel efficiency rating provides a unitless number that becomes the frequency based maximum payload fuel efficiency rating. These ratings are located on Table 13. Table 14 shows the sum of the maximum payload fuel efficiency rating for each origin compared to the optimal rating derived from the P-center model.

Table 13: Frequency Based Maximum Payload Fuel Efficiency Rating

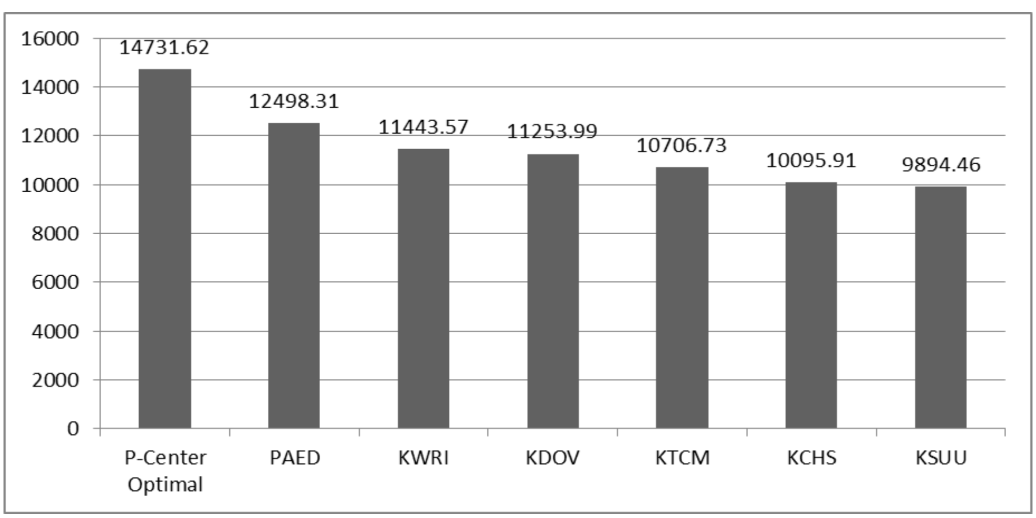
Destination	MAX	Count all MDS	C-17 Only	Count all MDS * MAX	C-17 Only*MAX
BGTL	0.84	420	4	352.8	3.36
EGUN	0.45	451	71	202.95	31.95
ETAR	0.38	9592	3594	3644.96	1365.72
FJDG	0.1	980	286	98	28.6
HDAM	0.17	390	51	66.3	8.67
HECA	0.24	142	3	34.08	0.72
LERT	0.42	2275	720	955.5	302.4
LICZ	0.33	302	1520	99.66	501.6
LIPA	0.34	680	18	231.2	6.12
LRCK	0.3	192	21	57.6	6.3
LTAG	0.25	5498	3021	1374.5	755.25
OAIX	0.2	3317	1220	663.4	244
OAKN	0.2	2066	1622	413.2	324.4
OAMS	0.21	200	67	42	14.07
OAZI	0.2	1665	1526	333	305.2
OBBI	0.2	1520	270	304	54
OKBK	0.21	1597	144	335.37	30.24
OTBH	0.19	2312	878	439.28	166.82
PGUA	0.29	1039	131	301.31	37.99
PHIK	0.65	3180	656	2067	426.4
PWAK	0.41	112	6	45.92	2.46
RJTY	0.47	2816	440	1323.52	206.8
RKSO	0.39	1588	50	619.32	19.5
RODN	0.32	1429	78	457.28	24.96
RPMZ	0.25	47	0	11.75	0
WSAP	0.19	1073	355	203.87	67.45
YSRI	0.15	359	347	53.85	52.05

Table 14: Maximum Payload Fuel Efficiency Rating Total for Each Origin



Using the P-center model allows the researcher to total the most optimal frequency based maximum payload fuel efficiency rating by summing the optimal rating of each destination from all 6 origins. The sum of the ratings in Table 13 is 14731.62 for all aircraft and 4987.03 for C-17s only. Since this number is unitless, its significance can be understood by comparing the frequency based maximum payload fuel efficiency ratings when the model was run by using only one origin instead of the most optimal of the 6 for each route. The results of the model run with only one origin is in Table 15.

Table 15: Frequency Based Maximum Payload Fuel Efficiency Rating for Individual Origins



When the maximum payload fuel efficiency ratings are multiplied by the frequency of use to each destination there were only minor changes. Most notably is that KSUU became the lowest scoring origin location when multiplied by frequency. Initially KSUU was the second lowest maximum payload fuel efficiency rating total, indicating that the most efficient routes from KSUU have not been utilized as frequently as its less efficient routes.

Investigative Questions Answered

1. Are there current C-17A bases that are not able to efficiently provide strategic airlift support the AORs of PACOM, CENTCOM, and EUCOM simultaneously?

Based on the research, KCHS, KSUU, and KTCM were found to produce insignificant results. KCHS and KTCM did not provide any optimal routes when run through the Route Analyzer to obtain the maximum payload fuel efficiency rating. When all of the maximum payload fuel efficiency ratings for all destinations are run, KCHS, KTCM, and KSUU score the lowest with 5.34, 5.9, and 5.41 respectively as reflected in Table 14. When frequency was added to the P-center model the scores for KCHS, KTCM, and KSUU are 10095.91, 10706.73, and 9894.46 respectively as reflected in Table 15. KSUU's frequency based maximum payload fuel efficiency rating score of 9894.46 is 33% lower than the P-center optimal score of 14731.62 when all bases were added to the model. After reviewing this data, it can be concluded that staging C-17A airlift operations out of KCHS, KTCM, and KSUU are inefficient compared to PAED, KWRI, or KDOV in order to serve all 3 AORs from the same location.

2. Does the use of polar routes increase the efficiency of strategic airlift operations servicing the AORs of PACOM, CENTCOM, and EUCOM?

To answer this question the results of the AFIT Route Analyzer model must be reviewed. Of the 6 origins studied for this research 3 bases, PAED, KTCM, and KSUU had optimized routes that traveled through the polar region. PAED had 14 of 27 of its routes travel through the polar region (Table 6), KTCM had 7 (Table 7) and KSUU had 1 (Table 8). All 3 US East coast bases did not use polar routing en route to any of their destinations. Since PAED's maximum payload fuel efficiency rating (Table 14) and frequency based maximum payload fuel efficiency rating (Table 15) were the highest for all the origins in this research it provides significant evidence that polar routing was essential for PAED to gain such high efficiency ratings. The fact that KTCM and KSUU also used polar routing but scored low on the efficiency ratings does not diminish from the utility of polar routing because the routes in which KTCM and KSUU used polar routing crossed close to PAED's location. PAED's departure routings to the same locations were more efficient because of its reduced distance to the destination.

3. Which US C-17A base can most efficiently provide strategic airlift support simultaneously to the AORs of PACOM, CENTCOM, and EUCOM?

PAED was the clear standout origin location based on the results of this research. Over 55% of the optimal routes to the 27 destination locations originated from PAED. PAED also scored the highest in maximum payload fuel efficiency rating (Table 14) and frequency based maximum payload fuel efficiency rating (Table 15) when set as the only origin. PAED's maximum payload fuel efficiency rating of 7.44 is 18% higher than the second best test subject base of KWRI which scored 6.1. Similarly, PAED's frequency based maximum payload fuel efficiency rating was 8% higher than that of KWRI's rating. After reviewing this data, it can be concluded that staging C-17A airlift operations out of PAED is the most efficient compared to the other 5 test subject bases.

Summary

Based on the assumptions of this research, the analysis shows that PAED is the ideal location to stage C-17A airlift operations in order to efficiently reach the most destinations in EUCOM, CENTCOM, and PACOM from the same origin. This capability is enabled by PAED's proximity to the polar region which allows the flexibility to efficiently reach multiple AORs from the same location. The research also shows that the 3 bases of KTCM, KCHS, and KSUU did not produce significant results and would be considered sub-optimal as a C-17A stage location to support all 3 theaters with regards to maximum payload fuel efficiency criteria.

V. Conclusions and Recommendations

Chapter Overview

This chapter discusses the basic conclusions about the research as well as provides recommendations for action and areas for further research.

Conclusions of Research

It can be concluded that Joint Base Elmendorf-Richardson is a uniquely situated airlift base. The data garnered from both the AFIT Route Analyzer and the P-center model support the researcher's first hypothesis (H1) that C-17A strategic airlift operations departing from PAED can most efficiently support EUCOM, CENTCOM, and PACOM destinations when compared to other US based C-17A locations. This research also supports the researcher's second hypothesis (H2) that PAED's location close to the polar route structure allows it to navigate to multiple AORs more efficiently than other US locations.

Significance of Research

This research can assist the Air Force and USTRANSCOM on the usefulness of using PAED as an airlift staging location. The reduced distance to most locations as well as its easy access to the polar region makes it a very strategic location. As the Air Force and AMC continue to formulate ideas on how to save fuel as well as reduce en route locations it is critical to use various methods of location theory to determine optimal staging locations.

Recommendations for Action

The Air Force, USTRANSCOM, and AMC should continue to study ways to exploit Joint Base Elmendorf-Richardson for its unique geographic position. Ramp space and throughput capacity should be studied and potentially bolstered in order to accommodate significant airlift operations. The Air Force should also review their en route locations to make sure that they are the most optimal for the destination locations within AORs. The US must also diligently maintain or renegotiate agreements with countries such as Russia to make sure that access to the polar region is not lost.

Recommendations for Future Research

There are several recommendations for future research. The first recommendation for future research is to simulate the use of other aircraft into the 2 model system in order to find additional location efficiencies that may exist based on the premise of this research. For example, the KC-10A would be an ideal test subject for route and P-center analysis due to its higher cruise speeds, range capability and cargo capability. The C-5M would be another viable subject aircraft due to its increased range and payload. The capabilities of both the KC-10A and the C-5M would help satisfy the desire of the Air Force to maintain fewer overseas locations as well as reduce en route stop infrastructure.

The second recommendation for future research is to determine the viability of using the P-center location model in future airlift basing considerations. Many times politics plays a heavy hand in where certain assets are assigned. Location theory techniques such as P-center modeling could provide useful data if a new round of the Base Relocation and Closure Commission is approved or if airlift units are reassigned.

The third recommendation for future research is to add additional factors into a more comprehensive basing study. The additional factors could also take into account the weather, base operations, ramp space, and cargo throughput of the test subject origin locations. These factors were not taken into account but would be beneficial in determining optimal staging locations.

The final recommendation for future research is to determine the viability of en route locations. Frequently the same en route location was identified by the AFIT Route Analyzer that is not commonly used by the Air Force. Lakselv Airport, Banak, Norway (ENNA) was identified 19 times (Table 6 and Table 7) as an efficient en route stop for the polar routes departing from PAED and KTCM. A small rotational stage force at locations like ENNA could enable USTRANSCOM to respond to emerging threats quickly. Further research should determine if ENNA is a viable en route stop that can be utilized by the Air Force for strategic airlift operations.

Summary

As world events continue to percolate in multiple theaters simultaneously, the Air Force must be poised to utilize airlift locations that have the flexibility to support multiple theaters. Although the defense budget has been decreasing, fuel prices have not. In order to tackle this problem the Air Force has been finding new ways to increase fuel efficiency. Greater utilization of strategic airlift from Joint Base Elmendorf-Richardson is a fuel efficient way of doing business particularly because of its access to the polar route structure.

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1. REPORT DATE (DD–MM–YYYY) 13-06-2014		2. REPORT TYPE Graduate Research Paper			3. DATES COVERED *(From — To)* May 2013 -- June 2014
4. TITLE AND SUBTITLE Over the Pole: A Fuel Efficiency Analysis of Employing Joint Base Elmendorf-Richardson for Polar Route Utilization					5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Sponseller, Hugh P., Major, USAF					5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way WPAFB OH 45433-7765					8. PERFORMING ORGANIZATION REPORT NUMBER AFIT-ENS-GRP-14-J-15
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Lt Col Stephen L. Hodge, 3 WG/IG 10480 Sijian Ave, Rm 153 JBER, AK 99506 DSN 317-552-2725 stephen.hodge@us.af.mil					10. SPONSOR/MONITOR'S ACRONYM(S) 3 WG/IG 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution Statement A. Approved for Public Release; Distribution Unlimited					
13. SUPPLEMENTARY NOTES This work is declared a work of the U.S. Government and is not subject to copyright protection in the United States.					
14. ABSTRACT The goal of this research is to determine which current US C-17A base is situated in the best geographic location to quickly and simultaneously support the Areas of Responsibility of Pacific Command, European Command and Central Command while providing the maximum cargo throughput in the most fuel efficient manner. The researcher hypothesizes that Joint Base Elmendorf-Richardson sits close to the potentially under-utilized polar route structure which could deliver fuel efficiencies. The research focused on the fuel efficiency rating of cargo missions originating from 6 US C-17A bases en route to numerous validated channel mission destinations. A maximum payload fuel efficiency rating is calculated by running each origin/destination pair through a Route Analyzer model. A weighted frequency based maximum payload fuel efficiency rating is then calculated by using a P-center location theory model ranking the 6 US bases by their overall score. Based on the assumptions of this research, the analysis shows that Joint Base Elmendorf-Richardson is the ideal location to stage C-17A airlift operations in order to efficiently reach the most destinations in Pacific Command, European Command and Central Command from the same origin due to its proximity to the polar route structure.					
15. SUBJECT TERMS Joint Base Elmendorf-Richardson, polar route, P-center, fuel efficiency					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Jeffery D. Weir, Ph.D., AFIT/ENS
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U	UU	63	19b. TELEPHONE NUMBER (Include Area Code) (937) 255-3636 Ext 4523 Jeffery.Weir@afit.edu

Standard Form 298 (Rev. 8–98)
Prescribed by ANSI Std. Z39.18